



(11)

**EP 1 996 738 B1**

(12)

**EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention  
of the grant of the patent:  
**01.04.2020 Bulletin 2020/14**

(51) Int Cl.:  
**C21D 8/10** (2006.01) **C21D 9/08** (2006.01)  
**C21D 9/14** (2006.01) **B21D 21/00** (2006.01)

(21) Application number: **07736718.3**

(86) International application number:  
**PCT/IT2007/000214**

(22) Date of filing: **23.03.2007**

(87) International publication number:  
**WO 2007/108038 (27.09.2007 Gazette 2007/39)**

**(54) PRODUCTION SYSTEM OF WELDABLE AND STAINLESS TUBULAR STRUCTURES WITH HIGH MECHANICAL STRENGTH AND PRODUCT OBTAINED THEREFROM**

SYSTEM ZUR HERSTELLUNG SCHWEISSBARER UND ROSTFREIER ROHRKONSTRUKTIONEN  
MIT HOHER MECHANISCHER FESTIGKEIT UND AUF DIESE WEISE HERGESTELLTES PRODUKT

SYSTÈME DE PRODUCTION DE STRUCTURES TUBULAIRES INOXYDABLES ET SOUDABLES  
AVEC HAUTE RÉSISTANCE MÉCANIQUE ET PRODUIT OBTENU ASSOCIÉ

(84) Designated Contracting States:  
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR  
HU IE IS IT LI LT LU LV MC MT NL PL PT RO SE  
SI SK TR**

(74) Representative: **Croce, Valeria et al**  
**Jacobacci & Partners S.p.A.**  
**Via Senato, 8**  
**20121 Milano (IT)**

(30) Priority: **23.03.2006 IT MN20060021**

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**JP-A- 1 123 026 JP-A- 11 158 551**  
**JP-A- 58 087 224 US-A- 6 136 109**

(43) Date of publication of application:  
**03.12.2008 Bulletin 2008/49**

(73) Proprietor: **GILCOTUBI S.R.L.**  
**20129 Milano (IT)**

• **DATABASE WPI Section Ch, Week 197434**  
**Derwent Publications Ltd., London, GB; Class**  
**M, page 21, AN 1974-61151V XP002449836 -& SU**  
**403 464 A (KOGANOV I E ET AL) 28 June 1971**  
**(1971-06-28)**

(72) Inventor: **OMODEO SALE', Serena**  
**I-20133 Milano (IT)**

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## Description

**[0001]** The present invention refers to a production system of weldable and stainless tubular structures with high mechanical strength and product obtained therefrom, particularly indicated for making cold-drawn stainless steel tubular elements, workable with different thicknesses and shapes, provided with high performances in terms of mechanical and weldability characteristics for the construction of light and ultralight structural frames destined for a dynamic use, such as for example those for competition vehicles like race cars, high-end bicycles and for aeronautics.

**[0002]** In particular, the structural frames mentioned above are those for which particular performances are requested, in addition to strength and reliability, of lightness and good behaviour in the presence of dynamic stresses, as is the case of the structures for competition vehicles and for aeronautics.

**[0003]** As is known, the steel structural frames for dynamic use traditionally consisted of multi-way tubes, made with different steel qualities, welded together or interconnected by metal connection elements.

**[0004]** One dynamic frame example is that employed for making bicycles.

**[0005]** The making of tubes, destined for high-end bicycle frames, requires that they are subjected to particular working (shaping and differentiation of the thicknesses, also along the same tube, by means of broaching and/or coning) so to obtain a weight reduction, while ensuring a good mechanical strength even near the weld, and to increase the consistency of the structure, conferring greater stiffness and not only for aesthetic and design reasons.

**[0006]** As already mentioned, the tubes in question are preferably connected to each other by means of welding. To make good level connections, maintaining the mechanical characteristics of the material even in the weld zone, it is necessary to weld with particular techniques. A first welding example used is that called TIG (where TIG stands for *Tungsten Inert Gas*). In TIG welding, an electric arc is used for heating and melting the metal: the electric arc is started between the electrode and the piece to be welded. A protection gas passes through the nozzle, protecting the welding bath and the tungsten electrode. The main object of the protection gas in TIG welding consists of protecting the hot zones and the melted zones of the piece, the weld material and the electrode from the negative influence of the surrounding air. Moreover, the protection gas influences the characteristics of the arc and the aesthetics of the weld. The TIG welding advantages include the high quality of the joints and the absence of slag and spatter. Another welding method is braze-welding. These techniques require a high degree of precision and involve refined welding methods even if considered of artisan type.

**[0007]** Other, more technologically evolved welding methods are known, such as electron beam or laser welding which are used for the production of components for the aeronautics and aerospace sectors but which are not employed in the bicycle sector.

**[0008]** In fact, for example, the electron beam welding can join two materials even of different nature with high precision, which causes perfect adhesion between them without requiring a weld line. But in addition to requiring a very high initial investment cost, and the use of electricity, the costs exponentially increase in proportion with the size of the object to be welded, resulting hence unacceptably high.

**[0009]** In addition to that illustrated above, the electron beam welding and laser welding are not adapted for joining pieces of a certain size, such as frames, and are so costly and demanding that they require excessive investments to be used in the sector of bicycle frame producers. Moreover, after the welding, the finished frame requires an additional heat treatment with consequent movement costs etc. which considerably increase the production costs.

**[0010]** In every case, the used welding techniques must not induce yielding or other situations of vulnerability, nor aesthetically negative effects.

**[0011]** Presently, all qualities of steel adapted for the construction of the frames mentioned above lead to problems of weakening of the mechanical characteristics at the welding site, which oblige the application of reinforcement elements near the junctions, or the use of tubular elements of greater thicknesses (excluding the steel tubular elements welded with the electron beam and laser techniques).

**[0012]** Other problems in the construction of dynamic frames emerge from the fact that, today, the most employed steel typologies (i.e. carbon steels like 25CrMo4), while having optimal mechanical properties, are subject to corrosion, which causes both external and internal deterioration of the tube with obvious negative consequences regarding the strength and durability. In order to prevent deterioration, protection and finishing interventions are necessary which consist of protective paints, which in any case do not protect the tube interior where the corrosion is destined to occur if not through special, costly technologies.

**[0013]** Due to the use of protective enamels, negative effects are produced with regard to the weight, in addition to overall environmental impact induced from the production and maintenance of the frame.

**[0014]** Among special non-stainless steels, capable of giving high performances in terms of elasticity, strength and lightness requirements, there is for example the steel 15CrMoV6, which is nickel-plated rather than painted; the corrosion protection is ensured in this case both outside and inside the tube. With the nickel-plating treatment, it is necessary to take into account the multiple negative effects which if not well controlled could cause further drawbacks. In fact, in the nickel-plating treatment, the negative impact is known which the electroplating activity has on the environment, due to

the emission of various toxic substances, like heavy metals, cyanides and strong acids (sulphuric acid, hydrochloric acid) with high environmental impact. The use of mineral salts, caustic substances and solvents in rather high quantities are a problem regarding both the waste waters and the waste disposal. Moreover, the formation of toxic vapours and powders coming from the working produces a considerable impact on the air.

**[0015]** Among other material not subject to corrosion, excluding aluminium and titanium (which do not belong to the category of materials referred to here and which have a series of specific, unresolved problems) and the ferritic stainless steels (characterised by poor mechanical characteristics and being liable to oxidation), a response to such problems was sought in the last decade in the stainless steels which however have not to date attained characteristics which are overall adequate for needs.

**[0016]** In fact, the austenitic stainless steels (such as for example AISI 304, AISI 308 etc.) have optimal weldability and stainless characteristics but poor mechanical properties; they are ductile but not hard, and (being monophasic) do not take to hardening: in fact, even with a fast cooling, after heating to temperatures greater than the transformation point (AC3), they do not change structure, remaining austenitic.

**[0017]** To confer greater mechanical characteristics to them, the stainless steels can be hardened with the treatment by mechanical stress (such as drawing, for example).

**[0018]** In this case, however, the problem tied to the welding step remains unresolved. By heating the material above the melting point, the neighbouring zones are also heated (and thus softened), which thus lose the acquired mechanical characteristics. The weld zone is configured as a further weak point. The attainable thinning of the thickness, to ensure strength to the structure, does not permit lightening the weight in an appreciable amount. Moreover, once hardened by drawing (or another mechanical stress), this type of steel has complex additional working problems.

**[0019]** While the chrome-nickel stainless steels cannot be hardened, the chrome martensitic stainless steels can be hardened.

**[0020]** In other words, in this type of steel, the austenite solubilised during the heat treatment and subjected to quick cooling generates a martensitic structure, attaining high mechanical characteristics.

**[0021]** The martensitic steel with Cr percentages greater than 13%, moreover, optimally resists corrosion. However, also in this case, problems arise tied to the welding step since in welding all martensitic steels are subject to the formation of microcracks (and in fact it is advisable to avoid this operation on steels with greater than 0.20% carbon content) which even if imperceptible compromise the strength, above all in the case of structures to be subjected to dynamic stresses. In any case, since they are self-hardening steels, it is always necessary to carry out a preheating before the welding and a tempering or an annealing immediately afterward. This aspect makes this material unfit and costly for the creation of tubes to be welded for the construction of greatly stressed frames for competition vehicles or for aircraft.

**[0022]** Presently on the market, there are also stainless steels hardening by precipitation (steel 17-4PH) which have good stainless steel qualities and have alloy elements (such as Al, Nb, Ti, Mo, Cu) such to cause, after the heat-aging treatment, the precipitation of hardening phases within the matrix, with the goal of bringing said steels to a high mechanical strength accompanied by a moderate tenacity and ductility.

**[0023]** As with the martensitic steels, these types of steels are also not easily subsequently reworkable, if not at very high costs.

**[0024]** Moreover, also in this case, the problem of weldability remains unresolved, since in the welding step the precipitation of the carbides is not produced. The formation of weak points during welding consequently makes the final structure less reliable.

**[0025]** Such problem can be avoided only with a further heat treatment, subsequent to the welding step, but which would lead to working problems with consequent additional costs.

**[0026]** Alternatively to the described steels, other stainless materials have been examined for the sector (such as, for example, the AerMet 100 alloy). The mentioned materials are characterised by more than one alloy element being present in greater than 5%, though they are not considered "alloys", intended in the traditional sense, but "super alloys" based on iron, cobalt, nickel (i.e. alloys in which the different mechanisms of structural modifications, which regulate the attainment of particular properties, are not due exclusively to the content of the additional elements but also to the complexity of the alloy itself).

**[0027]** In particular, these materials have a low modulus of elasticity and are of considerably more complex working than that required by steel. With such material, tubes are made, also drawn but always obtained by means of plate welding (and therefore never by billet extrusion). In addition to complex working and heat treatments, once made in a specific diameter and thickness (like the materials already described), they can no longer be modified if not at costs which would make the production uneconomical. Moreover, the consolidation of the frame points close to the weld must be carried out with the application of external reinforcement elements (gaskets).

**[0028]** A final mention is made, for the sake of completeness, to the possible production of tubes in Nanoflex, innovative steel obtained by nanotechnology, which thus has a completely different structure from the other steel categories.

**[0029]** It is a material which has considerable potentialities for the high mechanical characteristics (which are not obtained by heat treatments but by reduction percentage): theoretically, the tubes made in this steel can attain the best

mechanical, workability and finish characteristics examined up to now. But, apart from the fact that even Nanoflex has several problems during welding, this material is not yet commercially available. Furthermore, processes for manufacturing weldable tubular components by drawing and heat treatment made from austenitic and/or martensitic steels are disclosed in EP1288316, US6136109, JP58087224 and EP0916430.

**[0030]** Object of the present invention is substantially that of resolving the problems of the prior art by overcoming the above-described difficulties by means of a production system of weldable and stainless tubular structures with high mechanical strength and product obtained therefrom, capable of making tubes which cannot be attacked by corrosion, provided with high mechanical strength, easily workable for the obtainment of different thicknesses and shapes and easily weldable with limited weakness inductions near the weld.

**[0031]** A second object of the present invention is that of making a production system of weldable and stainless tubular structures with high mechanical strength and product obtained therefrom, capable of offering an improved technological response for the construction of light structural frames and welded tubular structures destined for dynamic use, obtained with tubes without welding and therefore structurally homogenous.

**[0032]** A third object of the present invention is that of having a production system of weldable and stainless tubular structures with high mechanical strength and product obtained therefrom which is capable of making tubes with high mechanical properties and optimal safety and quality standards, destined to give an improved technological response for making mechanical components subject to dynamic stresses, for use also in extreme conditions in which high performance characteristics are required, in sectors such as aerospace, aeronautics, nuclear, chemical, marine, motor sports and cycling.

**[0033]** Another object of the present invention is that of making a production system of weldable and stainless tubular structures with high mechanical strength and product obtained therefrom which has a high index of workability.

**[0034]** A further object of the present invention is that of making a production system of weldable and stainless tubular structures with high mechanical strength and product obtained therefrom which permits reducing many of the environmental problems tied to the entire lifecycle of the object: reducing the processes in the production step and consequent consumption of toxic-harmful substances; in the useful lifetime steps of the object ensuring the lengthening of the durability, raising of the safety conditions and eliminating the use of chemical substances for maintenance; and at the end of the useful lifetime, in the discard step, ensuring the total recyclability without any loss of the raw material characteristics (as instead occurs in the recycling of the soft metals).

**[0035]** Not the least object of the present invention is that of making a production system of weldable and stainless tubular structures with high mechanical strength and product obtained therefrom which is simply made and has a good functionality.

**[0036]** These objects and still others, which will appear more clearly in the course of the present description, are substantially attained by a production system of weldable and stainless tubular structures with high mechanical strength and product obtained therefrom, as disclosed in claims 1, 12 and the dependent claims thereof.

**[0037]** Further characteristics and advantages will be more evident from the detailed description of a production system of weldable and stainless tubular structures with high mechanical strength and product obtained therefrom, according to the present invention, made here below with reference to the attached pictures, provided only as indicative and hence non-limiting, in which:

- Figure 1 shows a (100x) microscope-enlarged image of the metal structure after the treatment with the production system of the invention;
- Figure 2 shows a (200x) microscope-enlarged picture of the metal structure after the treatment with the production system of the invention and broaching;
- Figure 3 shows a micrograph of the weld joint which depicts the two different structures of the metal after the welding in the junction point between two tubes;
- Figure 4 shows another (100x) microscope-enlarged image of the metal structure after the welding;
- Figure 5 shows a (50x) microscope-enlarged image of weld executed on the metal obtained with the system according to the present invention;
- Figure 6 shows a broken tube following a traction test;
- Figure 7 shows a microscope image of a weld;
- Figure 8 shows the junction by means of welding of tubes obtained with the production system according to the present invention;
- Figure 9 shows a frame made with tubes according to the production system of the present invention;
- Figure 10 shows a section of the weld for the metallographic analysis of figure 5;
- Figure 11 shows the comparison between the surface aspect of a tube of the prior art after an oil heat treatment and a tube of the same material treated with the system of the invention.

**[0038]** The process of the present invention provides for the use of a steel which can be defined, for its characteristics,

as "austenitic-martensitic"; in fact, its specific chemical composition has a carbon content and molybdenum content of an austenitic stainless steel, and a nickel and chromium content of a martensitic stainless steel. The austenitic-martensitic steel according to the invention will have a martensitic percentage which can even arrive at about 95%. For this reason, the process of the invention can also be applied to martensitic steel. One type of steel which is advantageously employed in the process of the invention is that called X4CrNiMo 16-5-1.

**[0039]** The production system of weldable and stainless tubular structures with high mechanical strength of the present invention is substantially composed of the following steps:

- hot working of a martensitic steel or austenitic-martensitic steel to make a rough tube (known as a "preform");
- creation of a tip which serves to make the end of the tube smaller, so that it can pass through the drawing equipment and can be coupled for drawing,
- annealing heat treatment which serves to soften the material and make it deformable,
- optionally, a mechanical test which permits establishing if the mechanical characteristics of the material are suitable for subjecting the tube to drawing,
- optionally, metallography which permits viewing the structure of the material to evaluate if it comes within already established parameters, so to be able to proceed with the drawing, otherwise the material must undergo an annealing operation for softening it so it can be worked,
- chemical preparation of the surfaces which serves for lubricating the contact surfaces of the tube with the drawing equipment and for preventing seizures,
- drawing which deforms the material in a permanent manner,
- final heat treatment which serves for reforming the structure of the steel which was deformed and for determining the desired final characteristics,
- straightening which serves for making the drawn and furnace-treated tube rectilinear,
- passivation which serves for inducing a compact oxide patina into the steel, which ensures its resistance to corrosion.

**[0040]** The process can then be completed by conventional passages such as the cutting of the tube thus produced into more easily manageable pieces, quality control and packaging.

**[0041]** The first step of the process is the obtainment of the "preform", which is the raw material from which one starts for carrying out the process according to the present invention. In more detail, the preform is a tube which is hot-worked (at about 1300°C) : it can be rolled with the wheels which form it or extruded with a press. The characteristics of the preform are typical of a working carried out at high temperature: oxidised surfaces, coarse tolerances, large thicknesses with respect to the diameter, possibility of having only standard dimensions.

**[0042]** The preform is composed of material at the hardened and tempered state, whose high mechanical strength would not permit its drawing. In order to reduce its mechanical strength, it is necessary to subject it to an annealing process in one step if in a static furnace (or shaft furnace, load furnace etc.) or in several steps if in continuous or muffle furnaces, with the goal of passing it through the drawing machine and thus reduce its diameter and thickness.

**[0043]** The annealing heat treatment used in the production system of the present invention is carried out in controlled atmosphere furnaces for avoiding that the material undergoes surface alterations, both externally and internally, and prevents any oxidation and decarbonation. With the term "controlled atmosphere" it is intended an atmosphere of inert gases (such as nitrogen, helium, argon, etc.) or a vacuum atmosphere. In particular, a particularly advantageous controlled atmosphere in the scope of the present invention is a gaseous mixture composed of about 50% nitrogen and about 50% reducing gas, in which the reducing gas is for example a gas containing hydrogen such as that obtainable by steam reforming.

**[0044]** More in detail, in the annealing heat treatment step which is carried out in continuous type furnaces, one must account for the weight of the tube, the speed and time of passage and the temperature in the different zones of the furnace in order to obtain the desired technical characteristics in the working material. The heat treatment is a preparation treatment of the material for the subsequent steps and workings.

**[0045]** The annealing step provides for a first heating step from ambient temperature to the annealing temperature, a treatment step at the annealing temperature and a cooling step.

**[0046]** The preheating from ambient temperature to the annealing temperature is carried out in times of generally less than 1 hour.

**[0047]** The annealing treatment is carried out at a temperature which varies between 600°C and 750°C, preferably between 650°C and 700°C. In particularly preferred embodiment of the invention, the annealing treatment is carried out at a temperature of about 680°C. The annealing treatment will be extended for a time of at least 1 hour, more preferably less than 3 hours. In a particularly preferred embodiment of the invention, the annealing treatment will be extended for about 1 hour and 20 minutes. The combination of treatment temperature and time is essential in order to obtain a material having the desired characteristics, i.e. high weldability together with optimal mechanical properties. In general, it can be affirmed that the treatment temperature is inversely proportional to the treatment time: if one operates at a temperature

close to the lower limit of the above-outlined range, it will therefore be necessary to prolong the treatment times.

**[0048]** The cooling of the annealed tube is an extremely important operation. A slow cooling in a controlled atmosphere is essential. Generally, cooling times are provided for between 2 and 4 hours.

**[0049]** Optionally, in order to verify that the material has the required characteristics and specifications for the subsequent steps, it is subjected to a mechanical test which permits establishing if the mechanical characteristics of the material are suitable for subjecting the tube to drawing and metallography for evaluating if the structure of the material comes within already established parameters, so to be able to proceed with the drawing; otherwise, the material will have to undergo an annealing treatment to soften it so it can be worked. These controls will not be routinely carried out, however, but only in the implementation step of the process on the selected martensitic or austenitic-martensitic steel.

**[0050]** At this point, the material is ready for the subsequent step which consists of the step of chemical preparation of the surfaces. The step in question consists of the immersion of the tube in a first tub containing a suitable acid (of nitric-hydrofluoric type) for a predetermined time (on the order of 40 minutes), rinsing in water in a second tub and a subsequent immersion in a bath of an oxalate salt for a pre-established time (on the order of 20 minutes) and a final immersion in a stearic ester (preferably in 3% by weight concentration) which serves for lubricating the outer surface of the tube. Preferably, for the acid treatment, 140 kg/m<sup>3</sup> are used of 56% nitric acid and 40 kg/m<sup>3</sup> of 38-40% hydrofluoric acid. For the oxalate treatment, the oxalate concentration will generally be in the range of 8 - 16% by weight.

**[0051]** At this point, the material is ready for the step of drawing, since the tip for engaging the tube to the equipment of the drawing machine was made at the beginning of the work cycle.

**[0052]** Drawing is a mechanical working which permanently deforms the materials, in the present case steel. It is executed cold and therefore at ambient temperature by means of a machine (the drawing machine) which forces the material, drawing it by one end, to pass through the drawing equipment which determines its final configuration. The drawing equipment, in the case of tubes, can be made to work both on the tube exterior and interior. The steel drawn by one end takes the form of the equipment in which it is drawn and made to pass through.

**[0053]** In the present production system, all of the equipment must be made of "hard metal" with greater strength characteristics than those of the material being worked.

**[0054]** In particular, in the drawing step of the invention, several passages are executed in order to obtain the desired thicknesses of the tubes, since at each passage one succeeds to obtain a thickness reduction of about 20%. The drawing speed also depends on the material thickness: in fact, if one starts with 5 mm - 1.75 mm thicknesses, the drawing speed is moderate while with smaller thicknesses it is lower.

**[0055]** The above-described drawing is that with mandrel, but other drawing technologies are obviously not excluded, like bar drawing or cold pilger rolling.

**[0056]** After every passage through the drawing machine, the material is preferably subjected to a subsequent heat treatment with a passage in a furnace, since otherwise the material would break with the risk of inclusions. Such heat treatment, called normalisation, is particularly advised once thin thicknesses of the tube have been reached (thicknesses less than 2 mm for a tube diameter of about 5 cm).

**[0057]** The material, before entering the furnace, is subjected to a cleaning operation for removing the lubricating residues. The cleaning is carried out by immersion in tubs containing a solution of surface-active substances and carbonate salts.

**[0058]** The normalisation is normally conducted at a temperature in the range of 950°C - 1150°C for a time greater than 10 minutes and less than 1 hour.

**[0059]** The material is generally subjected to different steps of drawing, cleaning, normalisation by furnace heat treatment and chemical preparation of the surfaces until the desired thickness is obtained.

**[0060]** Once the desired thickness of the tube is reached, the material is subjected to the step of final heat treatment which gives the mechanical characteristics to the material (mechanical strength, yield and elongation).

**[0061]** The final heat treatment of normalisation and stress relieving occurs - always in controlled atmosphere - with temperatures and stay times set as a function both of the geometry of the finished tube and the final mechanical and desired microstructural characteristics. The normalisation, as said above, will be carried out at temperatures in the range of 950°C - 1150 °C for a time greater than 10 minutes and less than 1 hour. It should be taken into consideration that for tube thicknesses greater than 2 mm longer treatment times could be necessary than for lesser thicknesses.

**[0062]** In the last normalisation step, the cooling modes are very important in order to determine a high quality product. Such heat treatment process is very different from the traditional heat treatments with cooling in oil carried out in traditional chamber or muffle furnaces. In fact, for cooling the steel more quickly, at present the incandescent steel (900°C) is immersed in ambient temperature oil. The oil's capacity to exchange heat is very high (the oil does not evaporate at 900°C) and there is therefore a drastic cooling. In this case, however, the surface of the tubes is in contact with oil and there is a "contamination" which causes oxidation, so that the tubes would require a tempering heat treatment which cannot be achieved on tubes with small thicknesses (less than 1 mm) since they would irreparably deform.

**[0063]** In accordance with the present production system, after the heat treatment, a step of rapid cooling is preferably

carried out which operates by means of forced cooling on the controlled atmosphere around the tube (in detail, the tube is not in contact with the cooling water) and a step of gradual cooling until the tube is brought to ambient temperature.

**[0064]** In particular, a refrigerated controlled atmosphere is used, for example by placing, inside the cooling zone downstream of the furnace, a cold-water jacket or tubing near the working tubes.

**[0065]** With an air cooling according to the prior art, the heat is more slowly eliminated from the steel and the cooling is slower, but with the above-described modifications carried out on the facility, a sufficient cooling speed is attained. In this case one is able to work in a controlled atmosphere, thus avoiding ruining the surfaces of the tubes. It is important that the tube being worked undergoes a sudden temperature lowering, from about 920°C (temperature at the furnace outlet) to about 450°C, in a time in the range of 30 seconds - 2 minutes, preferably about 1 minute.

**[0066]** In addition to the foregoing, the heating of the material serves so to be able to bring the steel to have a specific starting structure, chosen as a function of the desired end product.

**[0067]** Moreover, the stay time serves to ensure a certain homogeneity: i.e. since the entire volume of the steel is homogeneous and has the same structure.

**[0068]** Finally, the cooling serves to obtain specific structures and hence mechanical characteristics: as a function of the cooling speed, one can obtain different structures.

**[0069]** The production system according to the present invention, at this point, provides for the step of straightening the tube, to which the step of pickling and/or passivation follows. In this step, the tube is treated so to induce a compact chromium oxide patina onto the steel, which ensures its resistance to corrosion. The methods used are conventional and consist of an acid treatment with acid baths like those described above (pickling), followed by washing and by subsequent immersion in a less aggressive acid bath (for example, diluted nitric acid) to induce a passivation speed.

**[0070]** At this point, the tube is subjected to the step of cutting, in which it is brought to the desired length as a function of the subsequent structural needs and is then packaged for storage and sale. The cutting can also be advantageously carried out before the pickling and passivation step.

**[0071]** In the production system of the present invention, the previous operations are all carried out with a controlled atmosphere to prevent the oxygen from coming into contact with the tube surfaces, since at high temperatures the oxidation process is very reactive and amplified.

**[0072]** Once the production of the tube with the invention system has been completed, when two or more elements must be joined in order to obtain a frame, shown in figure 9, welding is carried out at high artisan level as illustrated in figures 3, 4, 7, 8 and 10.

**[0073]** The present invention thus attains the aimed objects.

**[0074]** In fact, the production system of tubular structures of the invention permits obtaining a tubular element with high mechanical properties and high quality and safety standards, destined to give the best technological response for making mechanical components subjected to dynamic stress, for uses even in extreme conditions, in which considerable performance characteristics are required in sectors such as aerospace, aeronautics, nuclear, marine, chemical, motor sports and cycling.

**[0075]** Moreover, the production system of tubular structures of the invention permits obtaining:

- an improvement of the quality of the structure, since in the final drawn tube the crystallographic structure is preserved of a martensitic steel but which is further improved, as shown in figure 1 where one sees a fine and homogenous structure (due to the heat treatment of normalisation in a controlled atmosphere), thus ensuring structural characteristics, and in particular strength to the final product which are appreciably better than both those of the starting material and those obtainable with the traditional heat treatments, in oil or water, which require a tempering heat treatment which can be difficult or even impossible to make on tubes of small thicknesses, as already mentioned above;
- a surface finish, outside and inside the tube, which is greatly improved with respect to the conventionally-treated tubes, as shown in figure 11 where there is a comparison between the two stainless tubes of the same type, one of which treated with oil and the other with the system of the invention with air: the first results deformed and slightly opaque, the second has maintained the original form and is perfectly glossy;
- maintenance of the size and shape characteristics;
- a reduction of the working waste and discards, the inevitable drawbacks with the traditional and current heat treatments are avoided, such as: discard formation due to deformations and breaking, need for further final treatment of tempering/stress relieving, need for final inner/outer surface treatment for removing the inevitable stains from heat and oxidation, shown in figure 11, and which require mechanical satin finishing or chemical work by means of acid attacks;
- a reduction of the negative environmental impact: in fact, the overall environmental impact of the production process is reduced since there are no more problems related to the disposal of the oil of the traditional heat treatments and of the acid substances necessary for the satin finishing operations, rendered obsolete by the quality of the obtained final product, which in order to be stabilised with high stainless characteristics, requires only a light process of

passivation at the end of the cycle.

**[0076]** In addition to that illustrated up to now, with the production system of the invention the negative impact is reduced tied to the need of paints. Moreover, with respect to common steels, the recovery and recycling of the material is considerably increased.

**[0077]** Advantageously, the system according to the present invention permits maintaining high weldability characteristics (as shown in figures 3, 4, 5, 6 and 7) and, specifically, due to the particular chemical composition of the material which ensures high weldability, microcracks are not caused in the welding process, as illustrated in figure 5. Figure 5 shows an enlargement of the HAZ (Heat Altered Zone) surrounding the weld line in which the metallurgic transformation of martensite is clearly shown to be very limited, while presenting this area with a martensitic structure and a second "mixed" structure zone (figure 4), formed by the welding heat. The weld line is well defined and lacks any type of defect.

**[0078]** The absence of microcracks explains how, during the mechanical traction tests, the overly stressed structure did not break at the weld but along the non-welded line of the tube (i.e. in the base material), as shown in figure 6.

**[0079]** Normally, the break points are determined at the welds (or near these), since greater material vulnerability is created due to the formation of microcracks, which create weak points.

**[0080]** To overcome this problem, and to confer greater safety conditions near the weld itself, one normally employs the solution of making differentiated thicknesses along the tube, increasing its thickness in these points or by applying reinforcements.

**[0081]** On the other hand, the weld quality obtained in the tubes described here simplifies the working process and also introduces new opportunities, permitting using the process of shaping with differentiated thicknesses according to new criteria, process destined to give different levels of desired stiffness (specific stiffness) in different points of the elements assembled together in order to improve the geometric stability of the frame while further reducing the weight.

**[0082]** To support the improved mechanical characteristics of the product obtained with the production system according to the present invention, a comparison was carried out between two of the best typologies of steels currently on the market and the product obtained with the system of the invention. The following table shows the obtained results.

|                                                             |                                                               |                                                               |                                      |
|-------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|--------------------------------------|
| 25CrMo4<br>tube frame                                       | 15CDV6<br>Tube frame                                          | Tube frame<br>according to the<br>invention                   | Innovative<br>elements               |
| Tensile strength<br>750 N/mm <sup>2</sup><br>Yield strength | Tensile Strength<br>1,050 N/mm <sup>2</sup><br>Yield Strength | Tensile Strength<br>1,300 N/mm <sup>2</sup><br>Yield Strength | Greater<br>mechanical<br>properties, |

|    |                                                                                    |                                                                                    |                                                                                                                                        |                                                                                                                                                                                |
|----|------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 5  | 450 N/mm <sup>2</sup><br>Elongation 20 %                                           | 850 N/mm <sup>2</sup><br>Elongation 18 %                                           | 1,000 N/mm <sup>2</sup><br>Elongation 16 %                                                                                             | weight being<br>equal.                                                                                                                                                         |
| 10 | Weldability on<br>minimum 0.6 mm<br>thickness                                      | Weldability on<br>minimum 0.5 mm<br>thickness                                      | Weldability on<br>minimum 0.4 mm<br>thickness.<br><br>Weldable with<br>traditional<br>technologies<br>(TIG, MIG and<br>braze-welding). | Possibility of<br>making lighter<br>structures.<br><br>Ease of making<br>the structures<br>themselves.                                                                         |
| 25 | Not resistant to<br>corrosion                                                      | Not resistant to<br>corrosion                                                      | Resistant to<br>corrosion                                                                                                              | Greater duration<br>over time of the<br>structures made<br>both in inert<br>environments and<br>in saline<br>environments or<br>in the presence<br>of organic acids<br>(sweat) |
| 50 | The structures<br>must be<br>protected, both<br>internally and<br>externally, with | The structures<br>must be<br>protected, both<br>internally and<br>externally, with | No treatment is<br>necessary, except<br>a light<br>passivation,<br>since this is                                                       | Appreciable<br>savings with<br>regard to the<br>protection costs,<br>lower                                                                                                     |

|    |                               |                               |                         |                                                         |
|----|-------------------------------|-------------------------------|-------------------------|---------------------------------------------------------|
| 5  | paint or galvanic treatments. | paint or galvanic treatments. | highly stainless steel. | environmental impact and lower weight of the structure. |
| 10 |                               |                               |                         |                                                         |

General characteristics:

**[0083]** The high modulus of elasticity of 211,000 Mpa - twice the value of that of a titanium tube and three times that of aluminium - permits making extremely light frames with a high degree of stiffness.

**[0084]** The optimal expansion coefficient - in the field  $20 \div 100^{\circ}\text{C} \leq 0.00001 \text{ mm}$  - ensures optimal geometric and dimensional stability of the structure during the useful lifetime.

**[0085]** Advantageously, the steel obtained with the present system is stainless and weldable with extremely reduced thicknesses, since the steel of the weld and that in the surrounding areas has the mechanical characteristics of the rest of the structure as it is heated during welding and then quickly cooled.

**[0086]** In addition to that shown above, the steel obtained with the production system according to the present invention can be worked with already existing machines and tools and with known technologies, permitting considerable savings in the tubular structure production costs.

**[0087]** Advantageously, with the system of the present invention, numerous environmental impact problems tied to the entire life cycle of the object are not encountered. In fact, in the production step the system involves a reduction of the processes and consequent consumption of toxic-harmful substances with respect to that which occurs in the prior art; in the useful lifetime steps of the object, a greater durability and an increase of the safety conditions are ensured, and the use of chemical substances for maintenance is eliminated; at the end of the useful life, in the discard step, total recyclability is ensured without any loss of the raw material characteristics (as instead occurs in the recycling of soft steels).

**[0088]** In addition to that stated up to now, the production system is quite versatile and is capable of offering a production with decidedly innovative and reliable characteristics, given that the tubular element is obtained by a billet-extruded material, it is hence without welding and is cold-drawn. Moreover, the tubular element puts together the high technical performances of the martensitic steels with the high weldability characteristics of the austenitic steels, and is therefore optimally weldable with TIG and MIG technologies of known type and without elaborate processes as occurs in the prior art to obtain welds with high strength and seal characteristics.

**[0089]** In particular, as already anticipated above, the obtained tubular element has high strength characteristics ( $1.000 \div 1.300 \text{ MPa}$ ), high modulus of elasticity (211,000 MPa, twice that of a titanium tube and three times that of an aluminium tube), an optimal dimensional stability ( $20 \div 100^{\circ}\text{C} - 0.0001 \text{ mm}$ ) and therefore geometric stability ensured over the time of use, it is easily workable obtaining the most varied shapes and thicknesses and has an excellent surface finish, in addition to the fact that, being highly stainless, it is free from degradation and wear over time.

**[0090]** Not the least advantage of the present invention is that the steel tube according to the invention is considerably practical in use, easy to make and with good functionality.

**[0091]** Naturally, numerous modifications and variations can be made to the present invention, all coming within the scope of the appended claims.

## Claims

1. A process for the production of weldable and stainless tubular structures with high mechanical strength, comprising the following steps in succession:

- annealing heat treatment of a tube preform in martensitic or austenitic-martensitic steel, comprising a first step of heating from ambient temperature to the annealing temperature, a step of annealing treatment at a temperature of about  $680^{\circ}\text{C}$  extended for a time of at least 1 hour and preferably less than 3 hours, and a step of cooling;
- chemical preparation of the surfaces for lubricating the contact surfaces of the tube with the drawing equipment;
- at least one drawing passage for deforming the material in a permanent manner; and
- a final heat treatment for reforming the structure of the steel which was deformed and for determining the desired final characteristics, which is conducted at a temperature in the range of  $950^{\circ}\text{C}$ - $1150^{\circ}\text{C}$  and for a time

greater than 10 minutes and less than 1 hour;

wherein said final heat treatment is followed by a step of rapid cooling and then by a step of slow cooling, wherein said step of rapid cooling is conducted by means of the contact of said tubular structure with a refrigerated, controlled gaseous atmosphere and provides for the temperature lowering of said tubular structure from about 920°C (temperature at the furnace outlet) to about 450°C, in a time in the range of 30 seconds - 2 minutes, preferably about 1 minute; and

wherein said steel is martensitic or austenitic-martensitic steel and is X4Cr-Ni-Mo 16-5-1.

2. The process for the production of tubular structures according to claim 1, comprising at least two drawing passages until the pre-established thickness is reached.
3. The process for the production of tubular structures according to claim 1 or 2, wherein in every drawing passage the thickness is reduced by about 20%.
4. The process for the production of tubular structures according to any one of the claims 1 - 3, comprising, after each of said at least one drawing passage, a step of normalisation heat treatment of said tubular structure.
5. The process for the production of tubular structures according to claim 4, wherein said step of normalisation heat treatment is conducted at a temperature in the range of 950°C - 1150°C and for a time greater than 10 minutes and preferably less than 1 hour.
6. The process for the production of tubular structures according to claim 1, wherein said step of heating from ambient temperature to the annealing temperature is conducted in a time less than or equal to 1 hour.
7. The process for the production of tubular structures according to any one of claims 1 to 6, wherein said step of cooling is conducted in a time in the range of 2 - 4 hours.
8. The process for the production of tubular structures according to any one of the claims 1 - 7, wherein said step of chemical preparation of the surfaces comprises the immersion of the tubular structure in a first tub containing an acid for a pre-established time, preferably on the order of 40 minutes, rinsing in water in a second tub and subsequent immersion in a bath of an oxalate salt for a predetermined time, preferably on the order of 20 minutes, and final immersion in a stearic ester, preferably in a concentration of 3% by weight for lubricating the external surface of the tubular structure, wherein, for the acid treatment, 140 kg/m<sup>3</sup> of 56% nitric acid and 40 kg/m<sup>3</sup> of 38-40% hydrofluoric acid are used and wherein, for the treatment with oxalate, the oxalate concentration will be generally in the range of 8 - 16% by weight.
9. The process for the production of tubular structures according to any one of the claims 1 - 8, wherein said tubular structure, before said final heat treatment step, is subjected to a cleaning operation for removing the lubricating residues, wherein said cleaning step is carried out by immersion in a solution of surface-active substances and carbonate salts.
10. The process for the production of tubular structures according to any one of the claims 1 - 9, wherein said heat treatments of annealing, normalisation and final heat treatment are executed in controlled atmosphere furnaces to avoid that the material undergoes surface alterations, both externally and internally, and to prevent any oxidation and decarbonation, wherein said controlled atmosphere is a gaseous mixture consisting of about 50% nitrogen and about 50% reducing gas, wherein the reducing gas is preferably a gas containing hydrogen such as that obtainable by steam reforming.
11. The process for the production of tubular structures according to any one of the claims 1 - 10, wherein said preform is a rough tube obtained by hot-working from a billet or other source of martensitic or austenitic-martensitic steel, preferably by extrusion and wherein said tubular structures, after said step of final heat treatment, are subjected to a step of pickling and/or passivation.
12. Tubular structure in martensitic or austenitic-martensitic steel, weldable and with high mechanical strength, obtained by means of the process according to any one of the claims 1 - 11, wherein said steel is X4Cr-Ni-Mo 16-5-1 and has a tensile strength > 1100 N/mm<sup>2</sup>.

## Patentansprüche

1. Verfahren zur Herstellung von schweißbaren und rostfreien rohrförmigen Strukturen mit hoher mechanischer Festigkeit, welches nacheinander die folgenden Schritte aufweist:

- Glühwärmebehandlung einer Rohr-Vorform in martensitischem oder austenitisch-martensitischem Stahl, welche einen ersten Schritt aufweist, von Umgebungstemperatur auf die Glühtemperatur zu erhitzen, einen Schritt der Glühbehandlung bei einer Temperatur von etwa 680°C, die sich für eine Zeit von wenigstens 1 Stunde und bevorzugt weniger als 3 Stunden erstreckt, und einen Schritt des Kühlens;

- chemisches Präparieren der Oberflächen zum Schmieren der Kontaktoberflächen des Rohrs mit dem Streckgerät;

- zumindest einen Streckdurchgang zum permanenten Verformen des Materials; und

- eine finale Wärmebehandlung zum Reformieren der Struktur des Stahls, der verformt worden war, und zum Bestimmen der gewünschten finalen Charakteristiken, die bei einer Temperatur im Bereich von 950°C-1150°C und über eine Zeit länger als 10 Minuten und kürzer als 1 Stunde durchgeführt wird;

wobei der finalen Wärmebehandlung ein rascher Abkühlschritt und ein langsamer Abkühlschritt folgt, wobei der rasche Abkühlschritt mittels des Kontakts der rohrförmigen Struktur mit einer gekühlten kontrollierten Gasatmosphäre durchgeführt wird und für die Temperaturabsenkung der rohrförmigen Struktur von etwa 920°C (Temperatur am Ofenauslass) bis etwa 450°C in einer Zeit im Bereich von 30 Sekunden bis 2 Minuten, bevorzugt etwa 1 Minute, sorgt; und

wobei der Stahl martensitischer oder austenitisch-martensitischer Stahl ist und X4Cr-Ni-Mo 16-5-1 ist.

2. Das Verfahren zur Herstellung rohrförmiger Strukturen nach Anspruch 1, das zumindest zwei Streckdurchgänge aufweist, bis die vorbestimmte Dicke erreicht ist.

3. Das Verfahren zur Herstellung rohrförmiger Strukturen nach Anspruch 1 oder 2, wobei in jedem Streckdurchgang die Dicke um etwa 20% reduziert wird.

4. Das Verfahren zur Herstellung rohrförmiger Strukturen nach Anspruch 1 bis 3, das nach jedem des zumindest einen Streckdurchgangs einen Schritt zur Normalisierungswärmebehandlung der rohrförmigen Struktur aufweist.

5. Das Verfahren zur Herstellung rohrförmiger Strukturen nach Anspruch 4, wobei der Schritt zur Normalisierungswärmebehandlung bei einer Temperatur im Bereich von 950°C-1150°C und für eine Zeit länger als 10 Minuten und bevorzugt kürzer als 1 Stunde durchgeführt wird.

6. Das Verfahren zur Herstellung rohrförmiger Strukturen nach Anspruch 1, wobei der Schritt des Erwärmsens von Umgebungstemperatur auf die Glühtemperatur in einer Zeit weniger als oder gleich 1 Stunde durchgeführt wird.

7. Das Verfahren zur Herstellung rohrförmiger Strukturen nach Anspruch 1 bis 6, wobei der Kühlschritt in einer Zeit im Bereich von 2-4 Stunden durchgeführt wird.

8. Das Verfahren zur Herstellung rohrförmiger Strukturen nach einem der Ansprüche 1 bis 7, wobei der chemische Präparationsschritt der Oberflächen aufweist: Eintauchen der rohrförmigen Struktur in ein eine Säure enthaltendes Gefäß für eine vorbestimmte Zeit, bevorzugt in der Größenordnung von 40 Minuten, Spülen von Wasser in einem zweiten Gefäß und anschließendes Eintauchen in ein Bad eines Oxalat-Salzes für eine vorbestimmte Zeit, bevorzugt in der Größenordnung von 20 Minuten, und letztendliches Eintauchen in einen Stearin-Ester, bevorzugt in einer Konzentration von 3 Gewichts-%, zum Schmieren der Außenoberfläche der rohrförmigen Struktur, wobei für die Säurebehandlung 140 kg/m<sup>3</sup> von 56%iger Salpetersäure und 40 kg/m<sup>3</sup> von 38-40%iger Fluor-Wasserstoff-Säure verwendet werden, und wobei, für die Behandlung mit Oxalat, die Oxalat-Konzentration allgemein im Bereich von 8-16 Gewichts-% liegen wird.

9. Das Verfahren zur Herstellung rohrförmiger Strukturen nach einem der Ansprüche 1 bis 8, wobei die rohrförmige Struktur vor dem finalen Wärmebehandlungsschritt einer Reinigungsoperation unterzogen wird, um die Schmiermittelreste zu entfernen, wobei der Reinigungsschritt durch Eintauchen in eine Lösung von oberflächenaktiven Substanzen und Karbonatsalzen ausgeführt wird.

10. Das Verfahren zur Herstellung rohrförmiger Strukturen nach einem der Ansprüche 1 bis 9, wobei die Wärmebe-

handlungen zum Glühen, Normalisieren und die finale Wärmebehandlung in Öfen mit kontrollierter Atmosphäre ausgeführt werden, um zu vermeiden, dass das Material Oberflächenveränderungen, sowohl extern als auch intern, unterliegt, um die etwaige Oxidation und die Dekarbonisierung zu verhindern, wobei die kontrollierte Atmosphäre ein Gasgemisch ist, bestehend aus etwa 50% Stickstoff und etwa 50% reduzierendem Gas, wobei das reduzierende Gas bevorzugt ein Wasserstoff enthaltendes Gas ist, wie etwa jenes, das durch Dampfpreformieren erhältlich ist.

11. Das Verfahren zur Herstellung rohrförmiger Strukturen nach einem der Ansprüche 1 bis 10, wobei die Vorform ein rohes Rohr ist, das durch Heißbearbeitung aus einem Barren oder einer anderen Quelle von martensitischem oder austenitischem-martensitischem Stahl erhalten wird, bevorzugt durch Extrusion, und wobei die rohrförmigen Strukturen, nach dem finalen Wärmebehandlungsschritt, einem Beiz- und/oder Passivierungsschritt unterzogen werden.
12. Rohrförmige Struktur aus martensitischem oder austenitischem-martensitischem Stahl, der schweißbar mit hoher mechanischer Festigkeit ist, erhalten mittels des Verfahrens nach einem der Ansprüche 1 bis 11, wobei der Stahl X4Cr-Ni-Mo 16-5-1 ist und eine Zugfestigkeit  $> 1100 \text{ N/mm}^2$  hat.

## Revendications

1. Procédé de production de structures tubulaires soudables et inoxydables avec haute résistance mécanique, comprenant les étapes suivantes successives :

- traitement thermique de recuit d'une préforme en forme de tube en acier martensitique ou austénitique-martensitique, comprenant une première étape de chauffe de la température ambiante à la température de recuit, une étape de traitement de recuit à une température d'environ  $680^\circ\text{C}$  pendant une durée d'au moins une heure et de préférence de moins de 3 heures, et une étape de refroidissement,
- préparation chimique des surfaces pour lubrifier les surfaces de contact du tube avec l'équipement d'étirage,
- au moins un passage d'étirage pour déformer le matériau de manière permanente, et
- un traitement thermique final pour reformer la structure de l'acier qui a été déformé et pour déterminer les caractéristiques finales souhaitées, lequel est mis en œuvre à une température dans la plage de  $950^\circ\text{C}$  à  $1150^\circ\text{C}$  et pendant une durée supérieure à 10 minutes et inférieure à 1 heure,

**caractérisé en ce que** le traitement thermique final est suivi d'une étape de refroidissement rapide et puis par une étape de refroidissement lent, l'étape de refroidissement rapide étant mise en œuvre par le contact de la structure tubulaire avec une atmosphère gazeuse commandée refroidie et faisant baisser la température de la structure tubulaire d'environ  $920^\circ\text{C}$  (température à la sortie du four) à environ  $450^\circ\text{C}$  dans un temps dans la plage de 30 secondes à 2 minutes, de préférence environ 1 minute, et

**en ce que** l'acier est un acier martensitique ou austénitique-martensitique et est X4Cr-Ni-Mo 16-5-1.

2. Procédé de production de structures tubulaires selon la revendication 1, comprenant au moins deux passages d'étirage jusqu'à ce que l'épaisseur préétablie soit atteinte.
3. Procédé de production de structures tubulaires selon la revendication 1 ou 2, **caractérisé en ce que**, lors de chaque passage d'étirage, l'épaisseur est réduite d'environ 20%.
4. Procédé de production de structures tubulaires selon l'une quelconque des revendications 1 à 3, comprenant, après chacun desdits au moins un passage d'étirage, une étape de traitement thermique de normalisation de la structure tubulaire.
5. Procédé de production de structures tubulaires selon la revendication 4, **caractérisé en ce que** l'étape de traitement thermique de normalisation est mise en œuvre à une température dans la plage de  $950^\circ\text{C}$  à  $1150^\circ\text{C}$  et pendant une durée supérieure à 10 minutes et de préférence inférieure à 1 heure.
6. Procédé de production de structures tubulaires selon la revendication 1, **caractérisé en ce que** l'étape de chauffe de la température ambiante à la température de recuit est mise en œuvre en un temps inférieur ou égal à 1 heure.
7. Procédé de production de structures tubulaires selon l'une quelconque des revendications 1 à 6, **caractérisé en ce que** l'étape de refroidissement est mise en œuvre en un temps dans la plage de 2 à 4 heures.

8. Procédé de production de structures tubulaires selon l'une quelconque des revendications 1 à 7, **caractérisé en ce que** l'étape de préparation chimique des surfaces comprend l'immersion, pendant une durée prédéterminée, de préférence de l'ordre de 40 minutes, de la structure tubulaire dans un premier bac contenant un acide, le rinçage dans de l'eau dans un deuxième bac et une immersion subséquente dans un bain d'un sel d'oxalate pendant un temps prédéterminé, de préférence de l'ordre de 20 minutes, et une immersion finale dans un ester stéarique, de préférence dans une concentration de 3 % en poids pour lubrifier la surface extérieure de la structure tubulaire, **en ce que**, pour le traitement acide, 140 kg/m<sup>3</sup> d'acide nitrique à 56 % et 40 kg/m<sup>3</sup> d'acide fluorhydrique à 38 à 40 % sont utilisés, et **en ce que**, pour le traitement avec de l'oxalate, la concentration d'oxalate est en général dans la plage de 8 à 16 % en poids.
9. Procédé de production de structures tubulaires selon l'une quelconque des revendications 1 à 8, **caractérisé en ce que**, avant l'étape de traitement thermique final, la structure tubulaire est soumise à une opération de nettoyage pour enlever les restes de lubrifiants, l'étape de nettoyage étant mise en œuvre par immersion dans une solution de substances tensioactives et sels carbonate.
10. Procédé de production de structures tubulaires selon l'une quelconque des revendications 1 à 9, **caractérisé en ce que** les traitements thermiques de recuit, de normalisation et de traitement thermique final sont mis en œuvre dans des fours à atmosphère contrôlée pour éviter que le matériau subisse des altérations de surface, aussi bien à l'extérieur qu'à l'intérieur, et pour éviter toute oxydation et décarbonation, l'atmosphère contrôlée étant un mélange gazeux constitué d'environ 50 % d'azote et d'environ 50 % d'un gaz de réduction, le gaz de réduction étant de préférence un gaz contenant de l'hydrogène tel que celui susceptible d'être obtenu par reformage à la vapeur.
11. Procédé de production de structures tubulaires selon l'une quelconque des revendications 1 à 10, **caractérisé en ce que** la préforme est un tube brut obtenu par le travail à chaud à partir d'une billette ou d'une autre source d'acier martensitique ou austénitique-martensitique, de préférence par extrusion, et **en ce que** les structures tubulaires, après l'étape de traitement thermique final, sont soumises à une étape de décapage et/ou de passivation.
12. Structure tubulaire en acier martensitique ou austénitique-martensitique soudable et inoxydable avec haute résistance mécanique, obtenue par le procédé selon l'une quelconque des revendications 1 à 11, l'acier étant X4Cr-Ni-Mo 16-5-1 et ayant une résistance à la traction supérieure à 1100 N/mm<sup>2</sup>.

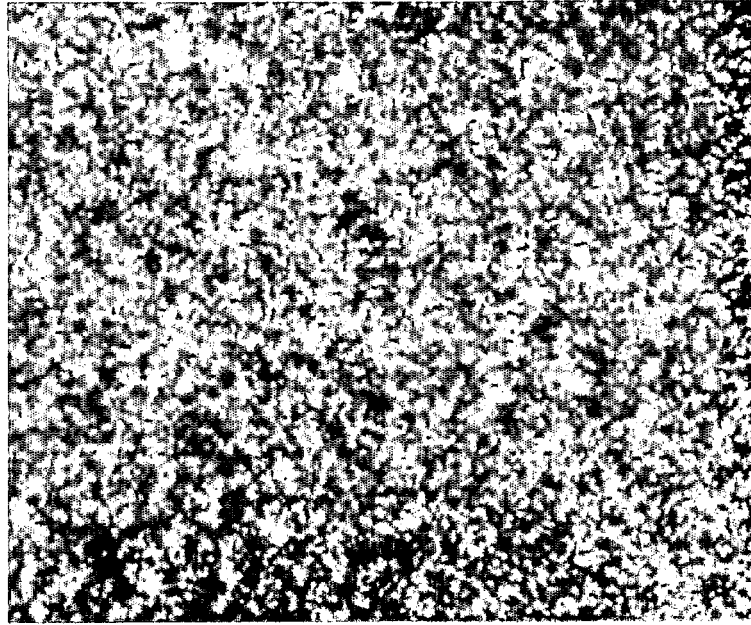


**FIG. 1**

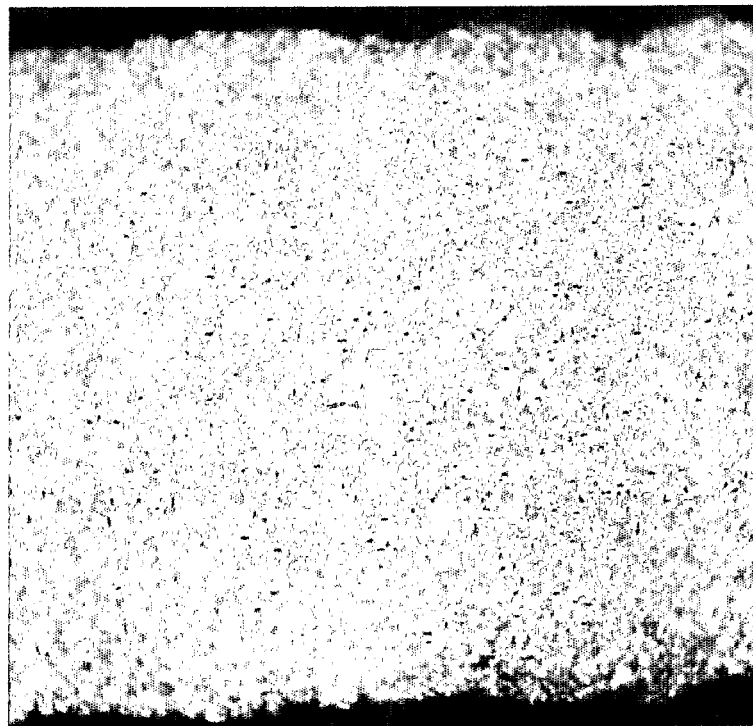


**FIG. 2**



FIG. 3

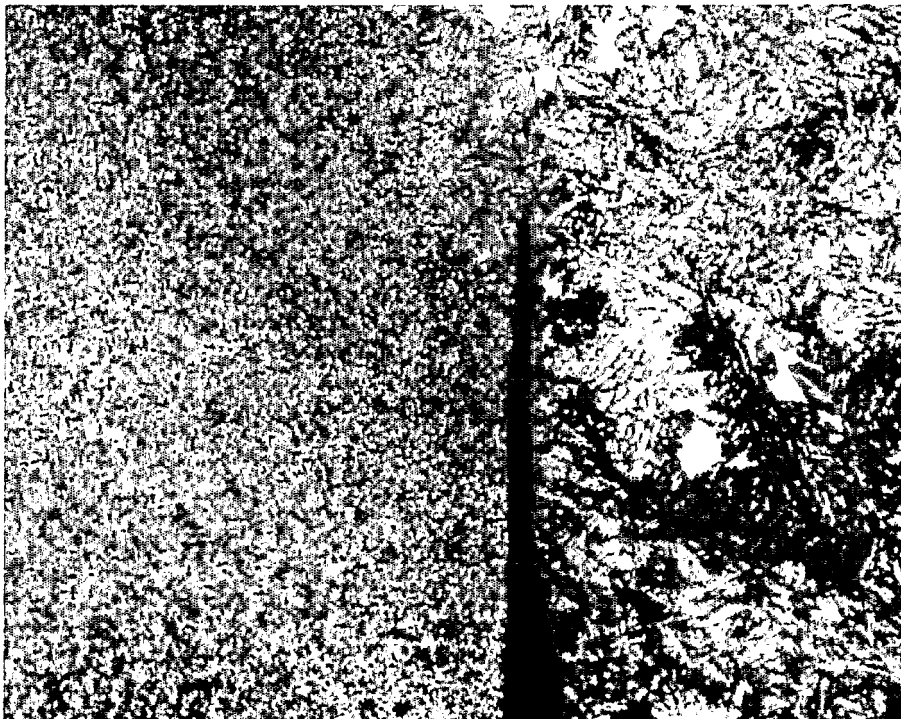


FIG. 4

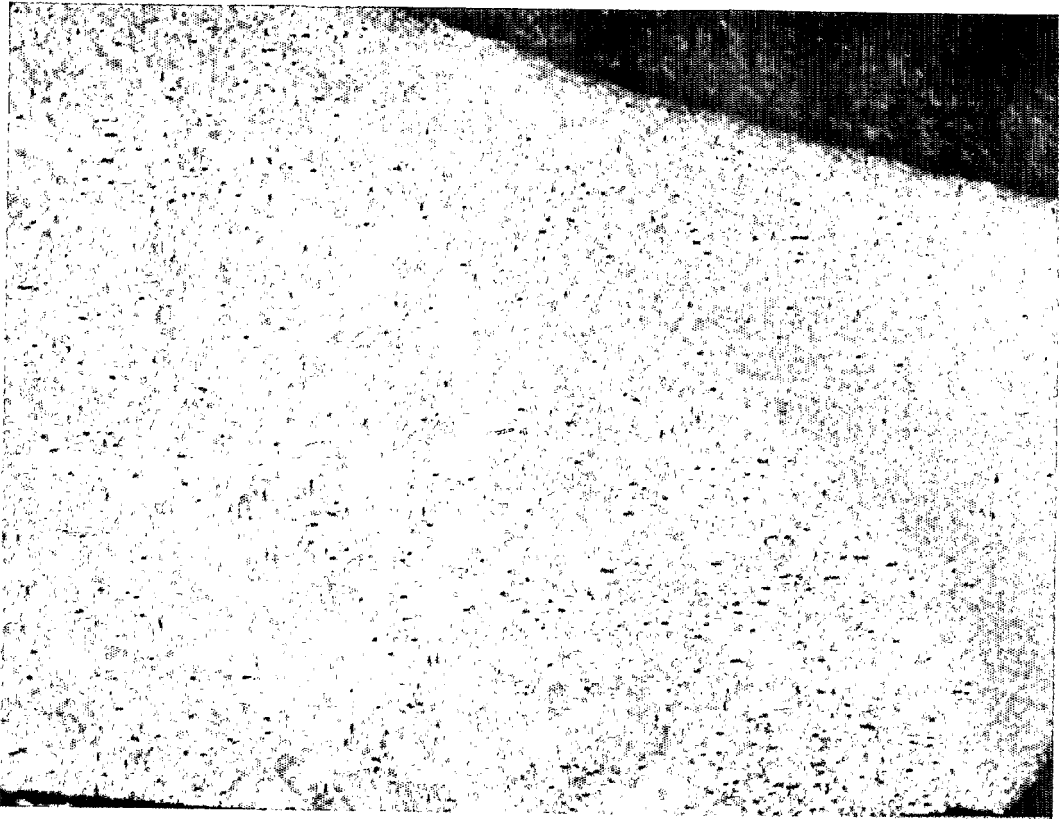


FIG. 5

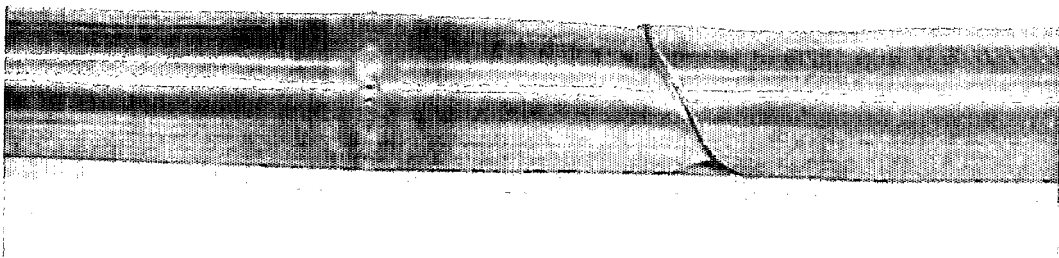


FIG. 6



FIG. 7

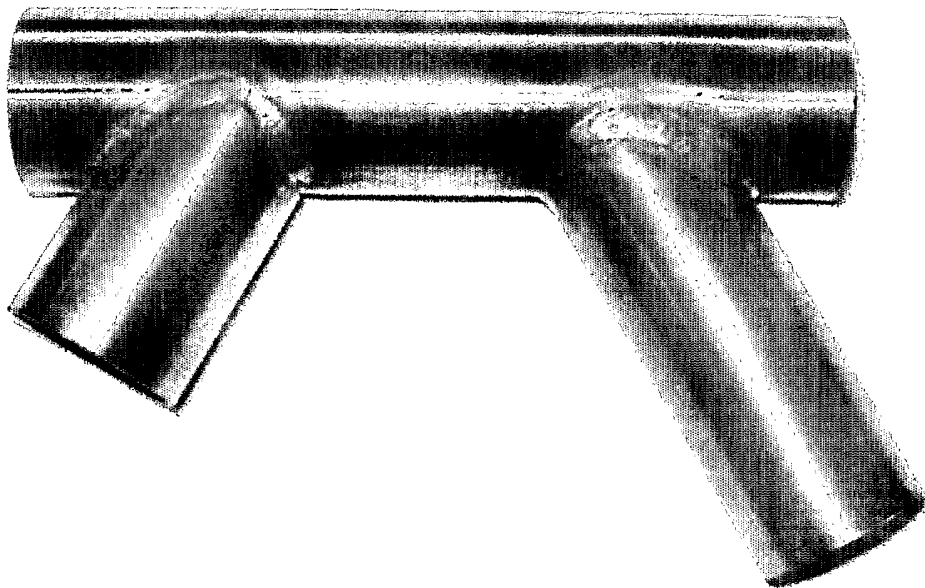


FIG. 8

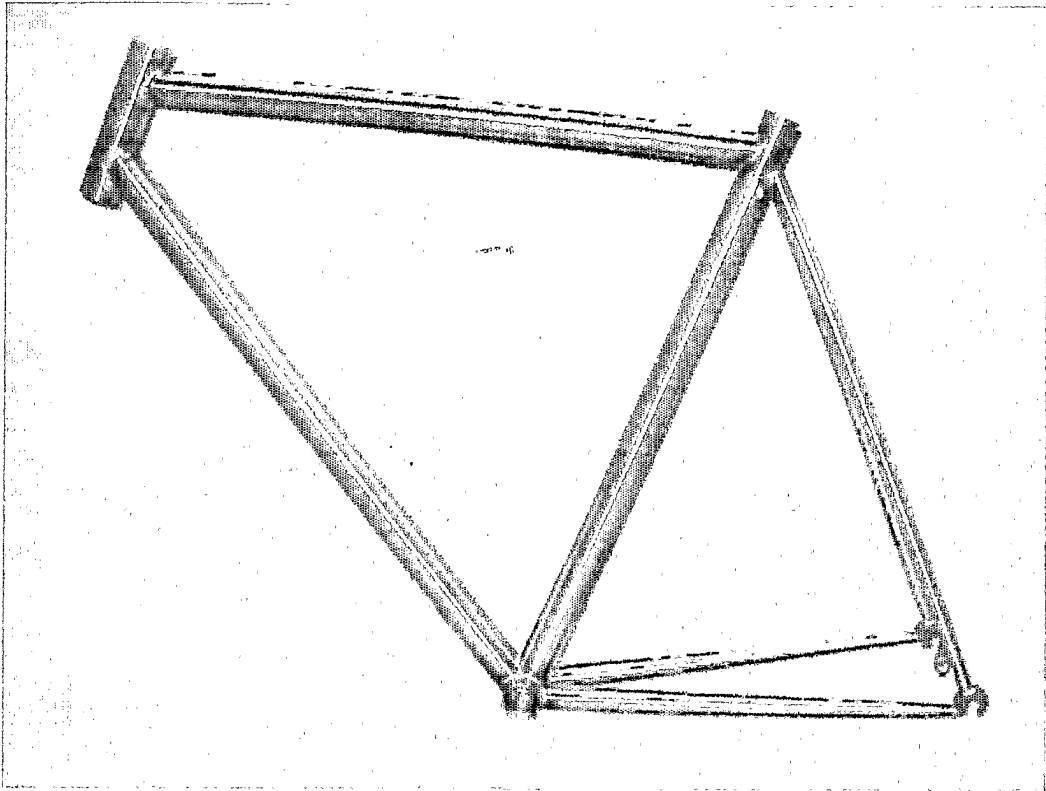


FIG. 9

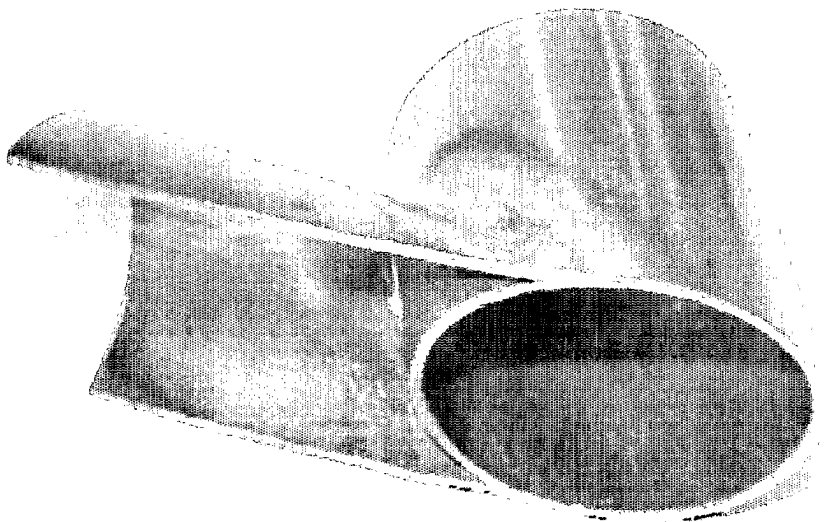


FIG. 10

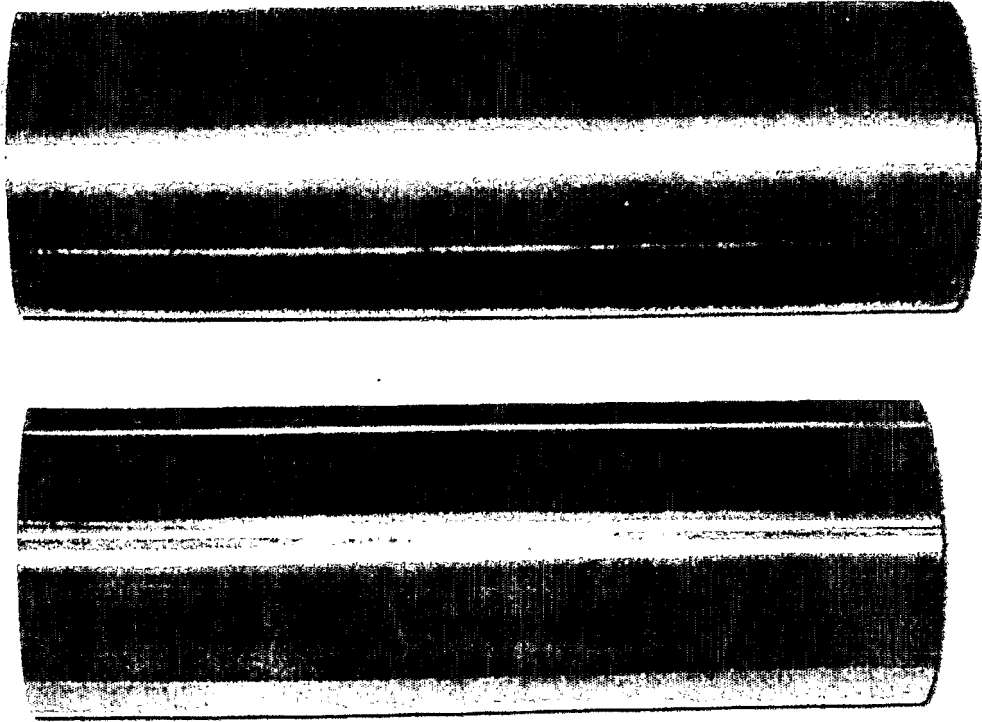


FIG. 11

**REFERENCES CITED IN THE DESCRIPTION**

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